THE SCIENTIFIC MONTHLY

JUNE, 1920

RECENT CALIFORNIA EARTHQUAKES[1]

By Dr. ANDREW H. PALMER

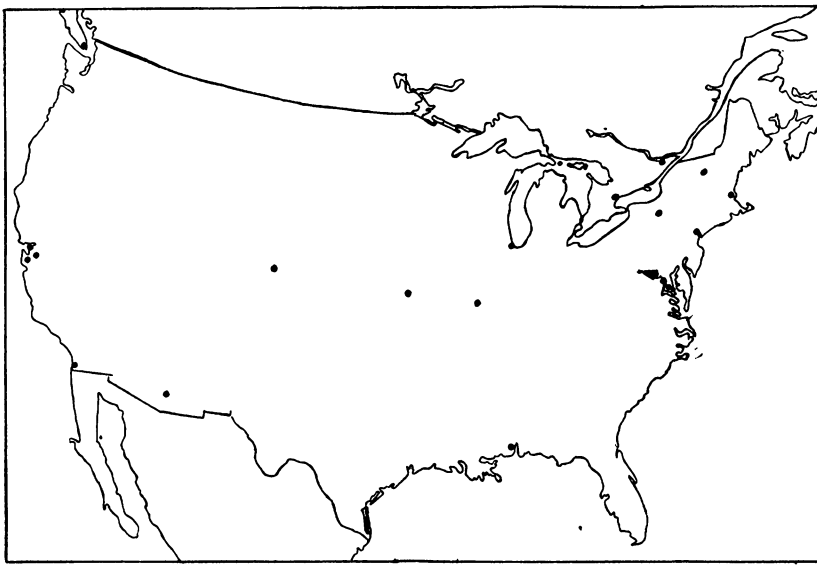
U. S. WEATHER BUREAU

PRIOR to 1906, little scientific investigation had been made of earthquakes in the United States. The great California earthquake of April 18, 1906, focused attention upon the subject, however, and ever since that time seismology has made steady progress. Following the San Francisco catastrophe, the Governor of California appointed a commission to investigate the phenomenon which had caused unprecedented damage, so far as an earthquake in the United States was concerned. This commission consisted of eminent scientists, and their report was, and still is, the most comprehensive seismological treatise ever published in this country.

In order that the widespread interest in the study of earthquakes which followed the San Francisco disaster might be crystallized, and productive of research, an organization was formed called the "Seismological Society of America." This organization has grown slowly but steadily, and to-day includes in its membership about 400 of the leading seismologists of the world. It investigates individual earthquakes, encourages seismological research, and publishes a quarterly journal which is sent to about 500 addresses.

The number of seismographs in operation in the United States has grown rapidly during recent years. While there are a few privately owned instruments, most are maintained by the United States Government or by educational institutions. The following is believed to be a complete list of public seismographs in operation in North America at the present time:

[1] Published with the permission of the Honorable Secretary of Agriculture.



OUTLINE MAP,
Showing all Places in the United States and Canada where Seismographs were in Operation in 1919.

Maintained by the U. S. Coast and Geodetic Survey:
- Cheltenham, Maryland.
- Honolulu, Hawaii.
- Sitka, Alaska.
- Tucson, Arizona.
- Vieques, Porto Rico.

Maintained by the U. S. Weather Bureau:
- Chicago, Illinois.
- Northfield, Vermont.
- Washington, D. C.

Maintained by the Government of the Panama Canal Zone:
- Balboa Heights, Canal Zone.

Maintained by the Government of the Dominion of Canada:
- Ottawa, Ontario.
- Toronto, Ontario.
- Victoria, British Columbia.

Maintained by Educational Institutions:
- Berkeley, California; University of California.
- Cambridge, Massachusetts; Harvard University.
- Denver, Colorado; Sacred Heart College.
- Georgetown, District of Columbia; Georgetown University.
- Ithaca, N. Y; Cornell University.
- Lawrence, Kansas; University of Kansas.

Lick Observatory; Mount Hamilton, California; Univ. of California.
Mobile, Alabama; Spring Hill College.
New York, New York; Fordham University.
St. Louis, Missouri; St. Louis University.
San Diego, California; Raja Yoga Academy.
Santa Clara, California; University of Santa Clara.

CARD USED BY CORRESPONDENTS OF THE U. S. WEATHER BUREAU IN REPORTING EARTHQUAKES.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU (SEISMOLOGY).

Cross out words and parts not applicable, and fill in all remaining spaces. Use other side, if desired, for additional description and information.

Date of earthquake: ...., 19....
Time of beginning (use railroad time): Hour .... min., ..., a. m., p. m.

Location of observer:
- On mountain, hill, plain, in valley.
- Outdoors, indoors, 1st, 2d, 3d, ... floor.
- State ...., town ....
- Street ...., No. ......
- If in country, distance ...., direction ...... from ....(nearest P. O. or town).

What doing: Lying down, sitting, standing, walking, ...
Onset of shocks: Abrupt, rapid, gradual.
Nature of shocks: Bumping, rocking, trembling, twisting.............
Intensity (give number, see scale on other side): ....
Number of shocks during earthquake: ....
Duration of each: ....
Direction of vibration: N.-S.; NE.-SW.; E.-W.; SE.-NW.
Sounds: No, yes. Before, with, after shocks. Faint, loud, rumbling, rattling.
Felt by: One, several, many.
Name of observer: ....
Address of observer: ....

(On back)

REMARKS.

EARTHQUAKE INTENSITIES. (Adapted Rossi-Forel.)

1. Felt only by an experienced observer, very faint.
2. Felt by a few persons at rest, faint.
3. Direction or duration appreciable, weak.
4. Felt by persons walking. Doors, etc., moved.
5. Felt by nearly everyone. Furniture moved.
6. Bells rung, pendulum clocks stopped. Alarm.
7. Fall of plaster, slight damage. Scare.
8. Fall of chimneys, walls cracked. Fright.
9. Some houses partly or wholly wrecked. Terror.
10. Buildings ruined, ground cracked. Panic.

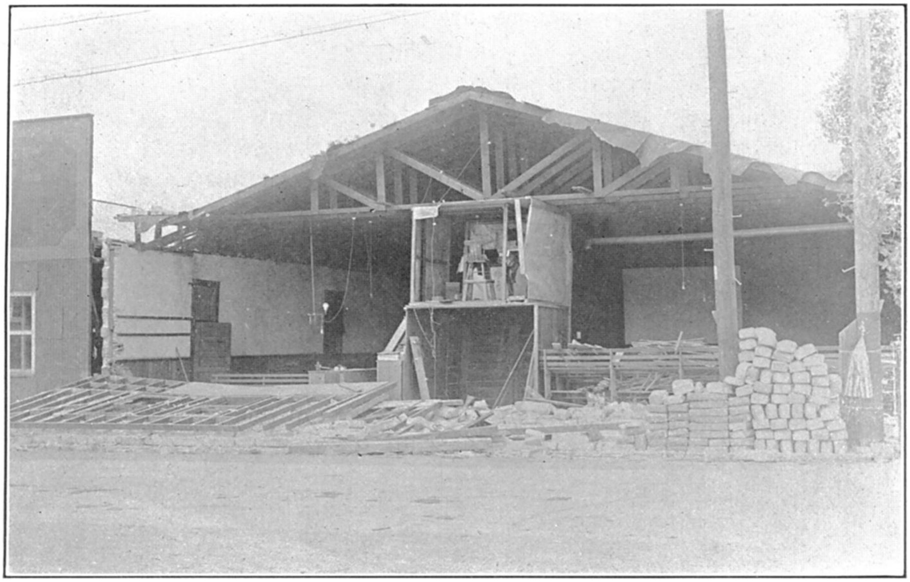


FIG. 1. A MOVING-PICTURE THEATER AT SAN JACINTO, CALIFORNIA, AFTER ITS FRONT WALL HAD FALLEN TO THE STREET DURING A RECENT EARTHQUAKE. The concrete-block type of construction is dangerous in a region of high seismicity. (Photograph by S. D. Townley.)

In accordance with a law enacted by Congress, the United States Weather Burean has collected and published reports of all earthquakes which have occurred in the United States since July 1, 1914. Besides the records obtained from its own seismographs, the Weather Bureau receives monthly reports of earthquakes recorded on the other instruments referred to above. Detailed reports are published in the *Monthly Weather Review,* an official publication. The seismological work of the Bureau is in charge of Professor William J. Humphreys.

Besides the work of collecting and publishing the reports of earthquakes automatically recorded, the Weather Bureau has inaugurated a novel work in collecting reports of all earthquakes strong enough to be felt by persons. Besides its regular weather stations, now numbering over 200, the Bureau has about 4,500 cooperative weather observers and special correspondents, most of whom are in the rural districts or in small towns and cities. Nearly all of these have volunteered to cooperate in the work of gathering earthquake statistics, a work which requires but a few minutes of the individual observer's time in the course of a whole year. The results in the aggregate are of great value, however. The system employed is very simple. Each observer is given a few cards, on each of which certain questions are printed. When an earthquake occurs in

his vicinity, he is expected to answer the questions on the card, so far as that particular earthquake is concerned, and to forward the same immediately to a designated office of the Bureau. The system has been in successful operation for the past four years.

Count de Montesus de Ballore, who has perhaps done more than any other seismologist in the collection of earthquake statistics, has concluded that of the two classes of earthquakes, seismologic and seismographic, the former are the more worthy of consideration. Seismographs sometimes record earthquakes which are of artificial origin, or are due to the wind or the surf, and are therefore not earthquakes in the usual sense. Moreover, they frequently record vibrations from distant shocks which are not directly related to the seismicity of the region in which the instrument is located. It is thus apparent that seismographic records are apt to err in excess. Seismologic records, on the other hand, include sensible earthquakes only, these alone being the ones with which the public at large is concerned. Records of this nature are more likely to have an error due to deficiency, since light, though sensible, shocks occurring during the night may pass unobserved.

Few, if any, earthquakes of sensible intensity have passed unobserved in California during the past five years. This systematic and complete collection and publication of all earth-

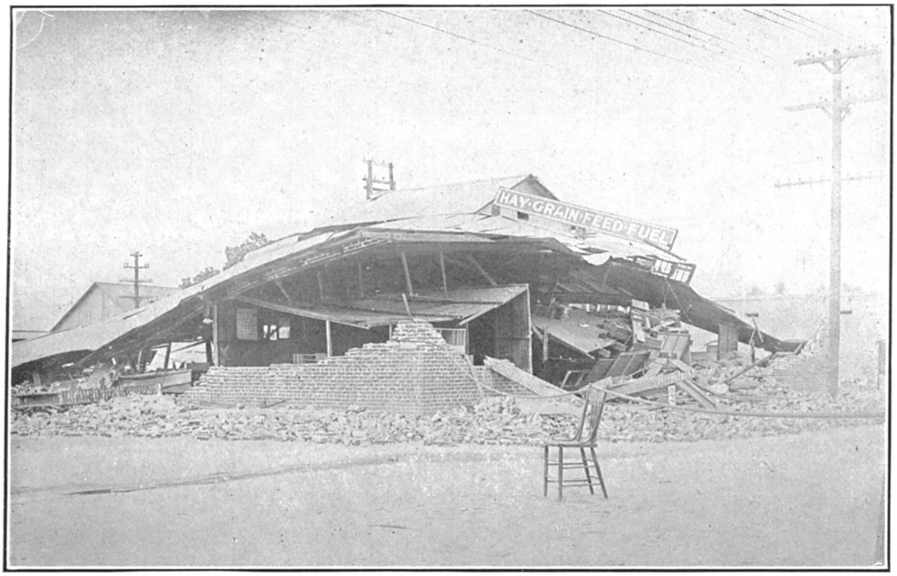


FIG. 2. AN EXAMPLE OF THE DAMAGE SUSTAINED BY BRICK BUILDINGS IN AN EARTHQUAKE. The reinforced concrete building shown in the right background was comparatively unharmed. (Photograph by S. D. Townley.)

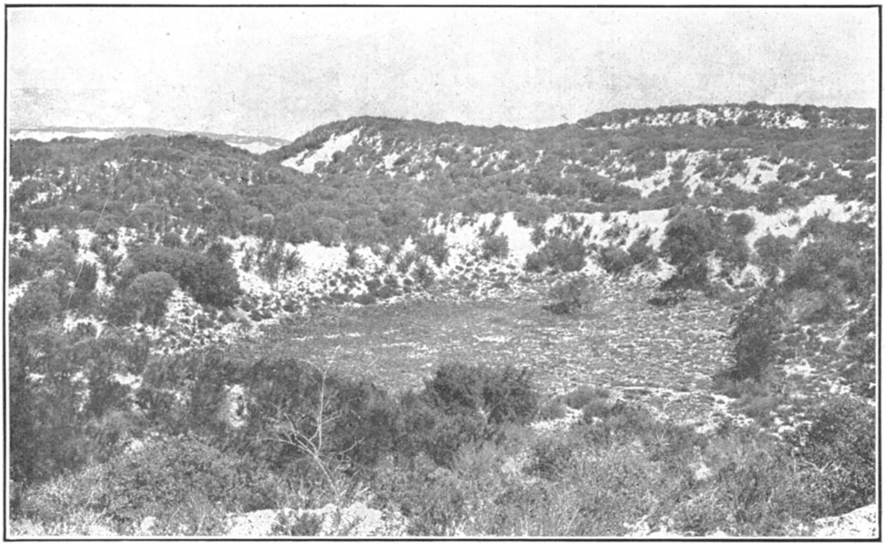


FIG. 3. A SAG-POND IN A SUNKEN AREA BETWEEN BAUTISTA CANYON AND THE SAN JACINTO RIVER, CALIFORNIA. All California earthquakes occur from the slipping and sliding of the earth's crust along fault planes, which are rifts or breaks in the rocks. Such a fault passes through this region, and the area is subject to frequent disturbances. (Photograph by Homer Hamlin.)

quakes strong enough to be felt by persons in California has resulted from the cordial cooperation of all those interested, principally through the following agencies: (1) The Weather Bureau has about 300 correspondents, well distributed throughout the state (see the accompanying figure), who report on cards all earthquakes felt. (2) The Seismological Society of America, whose headquarters are at Stanford University, receives many reports from its members, most of whom reside in California. (3) Mr. Homer Hamlin, a consulting engineer with headquarters in Los Angeles, has a large number of private correspondents in southern California who report to him all earthquakes observed.

The remainder of this discussion is based upon the reports of sensible earthquakes received through these various agencies during the four years, 1915–1918, inclusive. During this period California experienced 89 earthquakes per year, in the average. It is therefore readily apparent why California should be of unusual interest in seismology.

THE OCCURRENCE AND DISTRIBUTION OF EARTHQUAKES, 1915–1918

During the four years, 1915–1918, inclusive, California had a total of 357 earthquakes. With respect to the months of occurrence, these were as follows:

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1915	8	5	7	13	9	8	8	3	4	10	4	4	83
1916	4	5	2	1	6	4	6	12	8	6	6	6	66
1917	3	4	7	7	12	29	18	9	6	7	5	2	109
1918	2	3	11	24	11	13	12	8	4	3	5	3	99
Total....	17	17	27	45	38	54	44	32	22	26	20	15	357
Av......	4.2	4.2	6.8	11.2	9.5	13.5	11.0	8.0	5.5	6.5	5.0	3.8	89.2

It is readily apparent from the table that earthquakes are far more frequent in California during the summer dry season than during the winter wet season. The total number does not seem to vary greatly from year to year, the average being about 89 shocks. During every month of these four years, at least one earthquake was felt somewhere in the state.

It has long been recognized that earthquakes are more frequent at night than during the daytime, and the records of the past four years are no exception to the general rule. A study of 1405 California earthquakes which occurred from 1769 to 1915, inclusive, showed that on the average, there are two maximum and two minimum hours of occurrence. The extreme maximum occurs at 11 P.M., and the extreme minimum at 5 P.M. A secondary maximum occurs at 5 A.M., and a secondary minimum at 1 A.M. The double periodicity in the diurnal curve

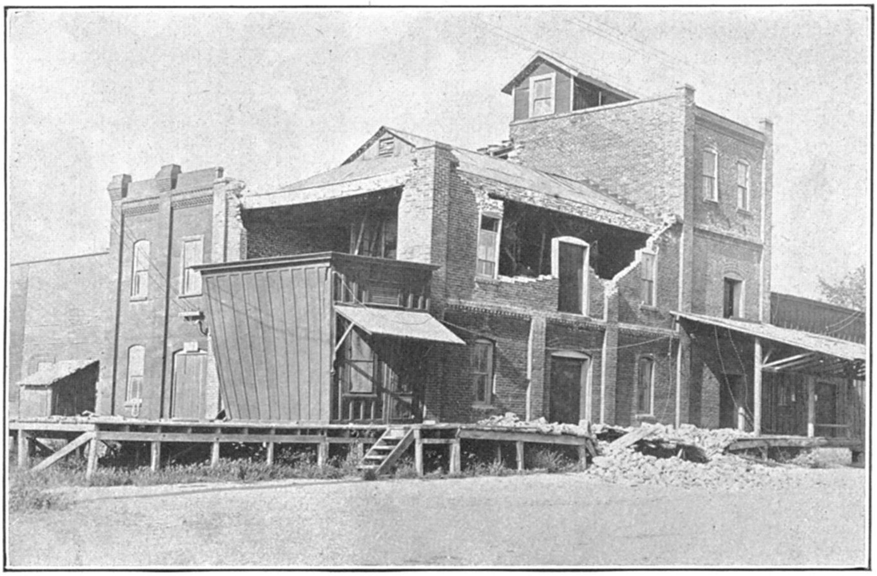


FIG. 4. A VIEW OF A FLOUR MILL AT HEMET, CALIFORNIA, SHORTLY AFTER THE EARTHQUAKE OF APRIL 21, 1918. Brick and adobe buildings can not withstand severe earthquakes, whereas reinforced concrete and steel frame buildings will stand through the strongest shocks. (Photograph by S. D. Townley.)

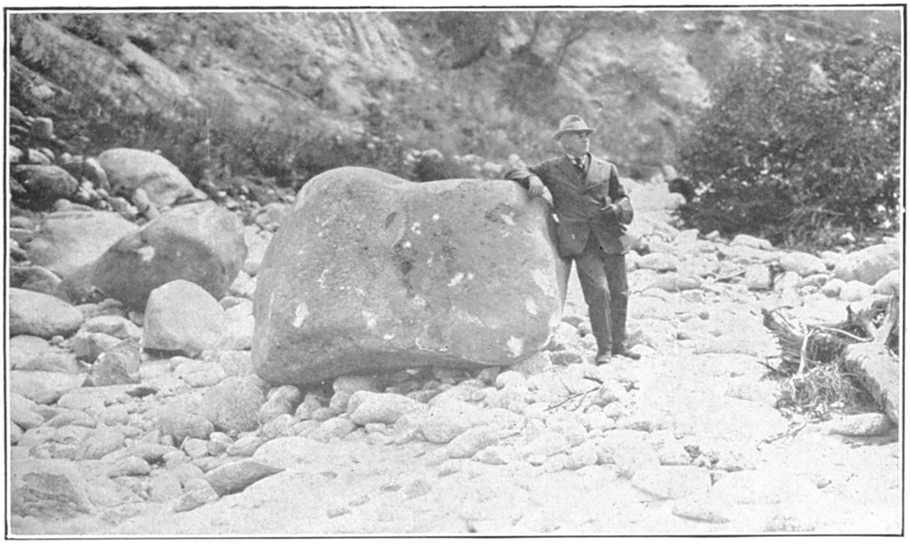


FIG. 5. AN EARTHQUAKE CAUSED THE BOULDER HERE SHOWN TO ROLL DOWN A MOUNTAIN SIDE IN CALIFORNIA. (Photograph by Homer Hamlin.)

reminds one of the diurnal curves of barometric pressure and of the tides of the ocean.

A region of high seismicity derives its instability from a number of causes, among which the following are the most important: (*a*) Folds in the earth's crust, either emerged or submerged; (*b*) marked variations of topography; (*c*) great ranges between ocean bottoms and adjacent mountain tops, as found where high mountains are close to a coast where the ocean bottom slopes precipitously to great depths; and (*d*) regions where secular elevation or depression is still in progress. All of these features are present in California, and collectively explain its high seismicity.

The real and ultimate cause of earthquakes is not understood. However, it is recognized that most earthquakes are related to movements of the earth's crust along vertical fault planes, which are simply breaks or rifts in the rock. These faults are numerous in California. The positions of those already recognized are shown in one of the accompanying figures. It is probable that in the course of time others will be discovered. There is a conspicuous parallelism in California, along NW.-SE. lines, of sea-coast, mountain chains, interior valleys, fault lines and earthquakes. Epicenters are found in a few places where the fault lines cross each other at right angles. Examples of these are the Monterey Bay region and

the region of the Tehachapi Pass. Other epicenters occur where there are great contrasts of topographic relief within short distances. Examples of these are the Owens and Imperial Valleys. The frequent occurrence of earthquakes along an E.-W. line passing through the San Francisco Bay region suggests an action of bending, or faulting, or both, in the depths of the crust about an axis in this direction. This might be expected if the southern Sierra Nevada were rising faster than the northern. The fault-block origin and structure of the Sierra Nevada contribute largely to the frequency of earthquakes in California.

At one time it was believed that volcanoes and earthquakes were closely related, and that the latter were simply due to movements of submerged lava in volcanic regions. However, while this may be true in Italy and in Hawaii, most seismologists now agree that there is complete independence of seismicity from volcanism, as far as the United States is concerned. The Milne-Omori investigation of 8,300 Japanese earthquakes which occurred between 1885 and 1892 showed little relation between earth shocks and volcanoes. Only about three per cent. of Japanese earthquakes are of volcanic origin.

Because it has within its borders the only active volcano in

FIG. 6. A VIEW OF THE FIRST NATIONAL BANK BUILDING AT HEMET, CALIFORNIA, JUST AFTER THE EARTHQUAKE OF APRIL 21, 1918. (Photograph by S. D. Townley.)

FIG. 7. BUSINESS HOUSES IN SOUTHERN CALIFORNIA LEVELLED TO THE GROUND IN A SEVERE EARTHQUAKE, WHICH CAUSED A PROPERTY LOSS ESTIMATED AT $300,000. (Photograph by Homer Hamlin.)

the United States, California offered a unique opportunity during the past few years to test the relation between a volcano and earthquakes. Lassen Peak (altitude 10,437 feet, Lat. 40° 25′ N., Long. 121° 45′ W.) broke forth in violent eruption in May, 1914, and has been active sporadically ever since, with more than 250 observed eruptions. Whether or not there has been any relation between the eruptions of Lassen Peak and California earthquakes, has been a much-debated question. Though the Weather Bureau has numerous seismological observers within a comparatively short distance of the mountain, the number of earthquakes reported in that vicinity was not large, comparatively speaking. It might be inquired whether the presence of an active volcano would tend to increase or to decrease the number of earthquakes. Humboldt found a tradition among the natives of South America that so long as the volcanoes in their neighborhood were active, no danger from earthquakes need be feared, but if these remained quiescent for a long-continued period severe earthshocks might be anticipated. In a manner the volcano acted as a safety-valve, according to the tradition. So far as it has been possible to determine, not a single earthquake occurred in northern California simultaneously with an eruption of Lassen, several press dispatches to the contrary, notwithstanding. As a matter of

fact, that part of the state farthest distant from Lassen Peak had the heaviest as well as the most numerous earthquakes.

It is probable that most, and perhaps all California earthquakes are due to slippings and slidings of the earth's crust for short distances along fault planes. The cause may be the strain imposed by some powerful force from without, or it may be simply the contraction of the earth itself. A tectonic rather than a volcanic origin is indicated by (*a*) the deep foci of the sensible shocks, (*b*) the long periods between the short preliminary tremors and the maximum vibrations, and (*c*) the vast areas over which the heavier shocks are felt.

California is not homogeneous in its seismicity, a fact which might be inferred from the distribution of faults, and from its topography. Earthquakes are frequent along the coast, and in the narrow Owens and Imperial Valleys. They are infrequent in the Sierra Nevada and Coast Ranges of Mountains, and they are rare in the Sacramento and San Joaquin Valleys. The San Andreas Rift, the longest and most conspicuous fault line in California, extends from Eureka, in extreme northwestern California, southeastward along the coast, through San Francisco, to detached southerly extensions in the Imperial Valley, and beyond the border of Mexico. The great earthquake of April 18, 1906, was due to a marked movement along this rift. As though the strain had been relieved by that movement, only a few shocks have since occurred along the northern portion of the fault. Eleven earthquakes occurred in San Francisco during the past four years. The Monterey Bay region showed marked seismicity, having had 23 shocks. The southern portion of this rift has been extremely active recently, and the Imperial Valley has been the most unstable region in the United States during the past four years. In fact, all of southern California south of the Tehachapi has shown marked seismicity, and the disturbances seem to be growing in frequency and in intensity. In the Imperial Valley a total of 70 earthquakes have been felt during the past four years, 26 having occurred in 1918 alone. In the city of Los Angeles, 30 earthquakes were felt in the four years, 17 of which occurred in 1917 alone. On the other hand, the Owens Valley, one of the recognized epicenters, has been comparatively quiescent. In this restricted region, where more than one thousand earthquakes occurred within a period of 48 hours on March 26–27, 1872, but 15 feeble shocks were felt during the past four years.

While the forecasting of earthquakes is as yet out of the

question, certain principles are recognized. It is thought that when a great earthquake occurs, the strain in the earth's crust is relieved through movements along the fault plane, and that the region then remains stable for a time. The infrequency of

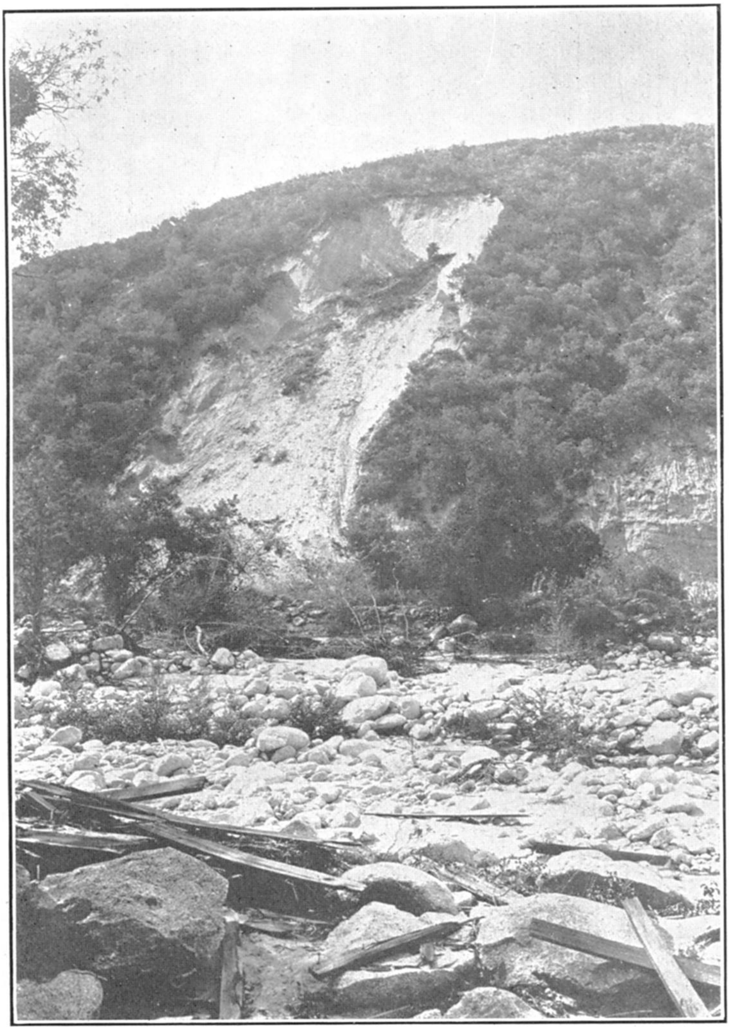


FIG. 8. A SCENE FIVE MILES SOUTHEAST OF VALLEVISTA, CALIFORNIA, SHOWING A LANDSLIDE CAUSED BY AN EARTHQUAKE. (Photograph by Homer Hamlin.)

shocks in San Francisco since the great disturbance of April 18, 1906, seems to verify this conclusion. On the other hand, some seismologists hold a theory that a great earthquake is preceded for months and years by an increasing number of

light shocks. The violent shock centering at San Jacinto and Hemet which occurred April 21, 1918, was preceded by a large number of minor disturbances, while but few have occurred since that time. The growing number of earthquakes in the Imperial Valley would seem to indicate that a great disturbance may be expected to occur there in the near future. This region may therefore be watched with interest during the next year or two.

THE INTENSITY OF EARTHQUAKES

The formula for seismicity involves the factors frequency and intensity. Of the two, the former carries the greater weight. It is generally recognized that the regions of most frequent earthquakes are also the regions having the severest shocks. Moreover, it is known that the intensity of an earthquake is directly proportional to the area shaken—in other words, the heavier the shocks, so much larger will be the area over which they will be felt.

An adapted Rossi-Forel scale of earthquake intensities is used by the Weather Bureau correspondents in reporting. In this scale of ten, the various intensities are described as follows:

I. Felt only by an experienced observer; very faint.
II. Felt by a few persons at rest; faint.
III. Direction or duration appreciable; weak.
IV. Felt by persons walking. Doors, etc., moved.
V. Felt by nearly everyone. Furniture moved.
VI. Bells rung; pendulum clocks stopped. Alarm.
VII. Fall of plaster; slight damage. Scare.
VIII. Fall of chimneys; walls cracked. Fright.
IX. Some houses partly or wholly wrecked. Terror.
X. Buildings ruined; ground cracked. Panic.

The late Professor Edward S. Holden, of the University of California, prepared the first catalogue of earthquakes on the Pacific coast, and the same was published by the Smithsonian Institution. From Professor Holden's study of the earthquakes of 129 years, 1769–1897, inclusive, he concluded that for any particular locality the number of really heavy shocks was quite small. The international reputation which certain cities bear as earthquake centers is, to a certain degree, unmerited. Thus at San Francisco there have been but three destructive shocks and four exceptionally heavy earthquakes in a hundred years, although there have been very many slight shocks and tremors. For the state at large, the most destruc-

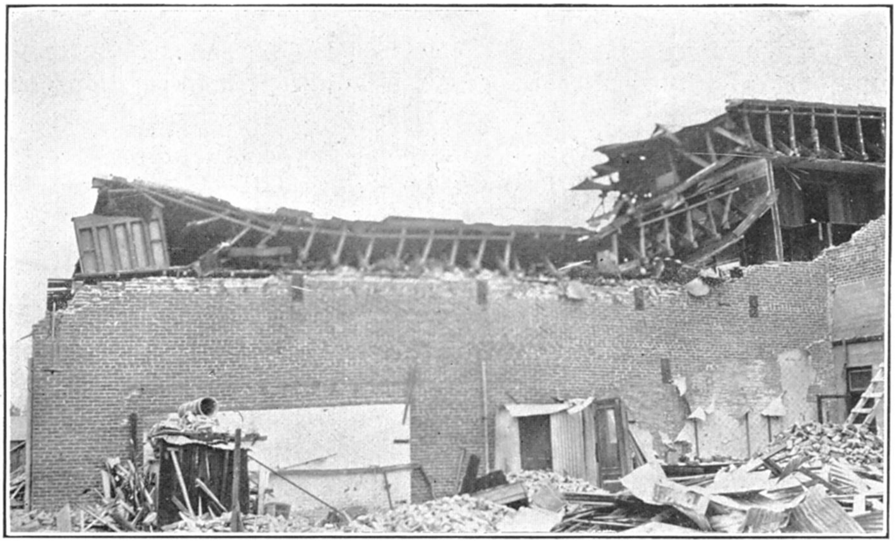


FIG. 9. MASONIC HALL AT SAN JACINTO, CALIFORNIA, wrecked in the Earthquake of April 21, 1918. Note the piano under the roof at the left. Brick buildings can not withstand severe earthquakes. (Photograph by Homer Hamlin.)

tive earthquakes in modern times have been those of 1800, 1812, 1872 and 1906.

During the past four years, two earthquakes of destructive intensity have occurred in California. The Imperial Valley earthquake of June 22, 1915, was accompanied by the loss of five lives, and the destruction of property in California and in adjoining portions of Mexico. A severe shock felt throughout southern California on April 21, 1918, appeared to center at San Jacinto and Hemet. Because of its fortunate occurrence at a time when most people in that vicinity were absent from business districts, and many were out of doors (2:32 P.M., on a Sunday), no lives were lost, but great destruction of property resulted, the loss having been estimated at about $300,000. (See effects in the accompanying photographs.)

Of those earthquake reports of the past four years in which an estimate of intensity was made by the reporters, the great majority of shocks were of feeble intensity, just strong enough to show their occurrence by rattling windows, swinging doors, or by moving furniture. In only a few cases was actual damage done. In each of two years, 1916 and 1917, the total property damage resulting from earthquakes in California was under $1,000. About 80 per cent. of the earthquakes of the past four years were so light that they were felt at one station

only, and not at two or more adjacent stations. Classified as to intensity, the California earthquakes of the past four years, so far as intensity estimates are available, are as follows:

	II	III	IV	V	VI	VII	VIII	IX	X
Number	111	197	172	128	27	9	16	8	2
Per cent	17	29	26	19	4	1	2	1	Less than 1

Number of Shocks in Each Earthquake

The typical earthquake consists of a series of preliminary tremors, one or more maximum vibrations, and a series of subsequent tremors. Reliable statements concerning the number of these maxima for any particular earthquake are, for psychological reasons, difficult to obtain. Concerning the attempts to secure such data in connection with the great earthquake of 1906, the California Earthquake Investigation Commission reported as follows:

> Many of these replies are rather questionable scientific evidence, inasmuch as many of them were in response to a leading and suggestive question, and very few of them have been subjected to the clarifying process of cross-examination.

While a seismograph would doubtless record many feeble vibrations in addition to the one or more strong enough to be

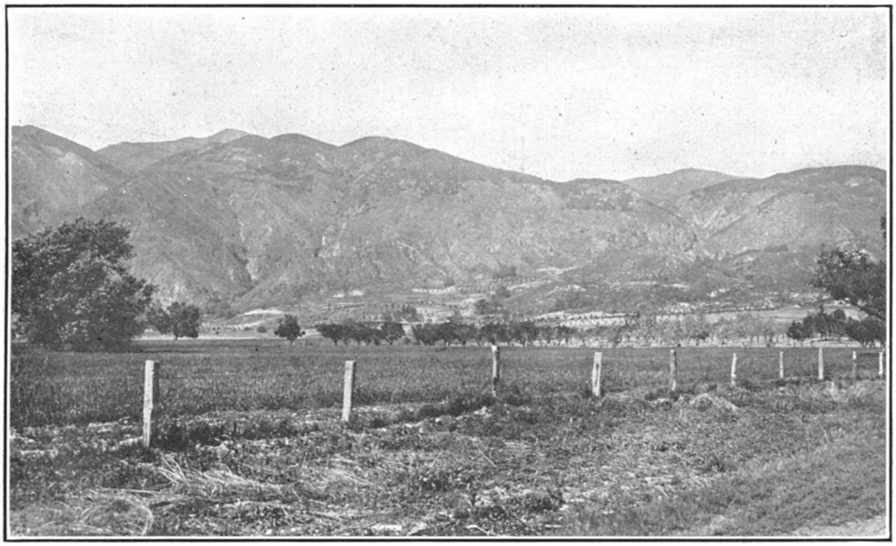


Fig. 10. A Fault Scarp in the San Jacinto Mountains about Two Miles East of San Jacinto, California, at Swoboda Springs. The fault plane here runs due east-west. (Photograph by Homer Hamlin.)

FIG. 11. A PHOTOGRAPH TAKEN IN THE BUSINESS DISTRICT OF SAN JACINTO, CALIFORNIA, FOLLOWING THE EARTHQUAKE OF APRIL 21, 1918. The center building was the telephone office. Note the difference in the damage sustained by the brick and the frame buildings here shown. (Photograph by S. D. Townley.)

felt by persons, the great majority of California earthquakes consist of but one sensible shock. An analysis of those reported during the past four years showed that 76 per cent. of them consisted of but one sensible shock; 17 per cent. of them consisted of two shocks; 5 per cent. of three shocks; 1 per cent. of four shocks; and less than one per cent. of five or more shocks.

DURATION OF EARTHQUAKES

The exact duration of the sensible earthquake can be determined accurately only by an acute observer equipped with a chronometer. While no such high degree of accuracy is here presumed, the testimony of the observers regarding duration is interesting, nevertheless.

Estimates ranged from a fraction of a second to more than a minute. It has been pointed out that the longer an earthquake lasts the greater will be its destructive effects. This is well borne out by the fact that the heaviest and most damaging earthquakes which have occurred in California during recent years were estimated to have lasted 60 seconds or more, in each case. On the other hand, most of the lighter shocks, those felt at one station only, were of but one to three seconds in

duration. The former are general and ruinous, the latter are local and harmless.

Some of the observers felt incompetent to estimate the duration of an observed earthquake in seconds of time, and for this reason the record for duration of shocks is somewhat incomplete. However, a considerable number of estimates of duration were received. These have been classified as follows:

Seconds	1 or Less	2	3	4	5	6–10	11–20	21–30	31–40	Over 40
Number	77	56	39	27	53	67	44	29	8	30
Per cent.	18	13	9	6	12	16	10	7	2	7

Sounds Accompanying Earthquakes

Ever since the time of Moses, descriptions of earthquakes refer to sounds accompanying these disturbances. The Scriptures are full of such allusions, and nearly every earthquake is said to have been accompanied by a great noise.

Psychological considerations play a prominent part in impressions of accompanying sounds. It is a well-recognized fact that people differ widely as to the range of audibility. Earthquakes which produce sounds observed by some persons may be apparently without sound to others. Personal equation, therefore, is important in this connection. Many persons are thrown into a peculiar kind of hysteria by experiencing an

Fig. 12. The Road between Hemet and Idylwild, California, blocked by Landslides in the Earthquake of April 21, 1918 (Photograph by Homer Hamlin.)

earthquake. Thunderstorms affect other people in the same manner. Generally speaking, the first earthquake one experiences does not produce hysteria. But if one passes through a disastrous earthquake, and suffers physical injury as a result of it, an earthquake subsequently experienced may easily cause hysteria through subconscious memory and association. When the observer is in such a disturbed state of mind, his impressions regarding sound are unreliable.

While it is possible that a few of the reporters were so influenced, the statements of accompanying sounds are not to be disregarded on that account. When sounds accompany earthquakes in California, they are usually of low pitch, that is, of relatively slow vibrations. The sounds may come from the ground or from the air, or from both. It was found that of the 357 earthquakes which occurred in California during the four years here considered, 34 per cent. were reported to have been accompanied by sounds. Of these, 65 per cent. were described to have been accompanied by rumbling, 17 per cent. by faint, indescribable sounds, 9 per cent. by loud sounds, 6 per cent. by rattling, 3 per cent. by roaring, and a few scattering reports included such expressions as explosive, tearing and shrieking. Some of these sounds occurred immediately before the earthquake, some were simultaneous with it, while some occurred immediately afterward.

General Considerations

Certain facts in connection with California earthquakes are of peculiar interest. For example, many and varied phenomena were caused by two widely-felt shocks which occurred at 6:44 and 6:55 P.M. on October 22, 1916. They were the strongest shocks felt in the state during the year, and they were observed throughout central and southern California. Of the 17 different stations from which reports were received, sounds were noted at but one, and in that instance the sound was described as faint. Waves 8 to 10 inches high rolled in on the west side of Buena Vista Lake for at least one hour after these shocks, and there was no wind blowing at the time. Near Maricopa, in the Kern County oil-fields southwest of Bakersfield, an oil-well that had been dormant for more than two years suddenly resumed its flow. The Edison Company's power line between Bakersfield and Los Angeles was broken. At San Bernardino the patients in the county hospital became so badly frightened that some time elapsed before they could be calmed.

A certain deep well located in the San Joaquin Valley temporarily became a geyser, and in the water ejected there were found a number of small fish without eyes, similar to fish which inhabit subterranean waters.

Temporary geysers are of frequent occurrence in a region of great seismicity. Preceding the San Diego earthquake of June 24, 1919, there was a marked disturbance of the Salton Sea, in Imperial Valley, a body of water formed twelve years ago when the Colorado River overflowed its banks and coursed into a part of the valley, most of which is below sea level. This disturbance, which occurred just before the earthquake felt at San Diego, 100 miles to the west, consisted of prolonged eruptions, for an hour or more, of a number of mud geysers, which tossed a mixture of mud and water, pearl gray in color, to a height of 60 feet. Geologists who have studied the valley have a theory that the geysers, which have erupted before, but never to such a height or for so long a time, serve as vents for gases formed far below the silt which forms the soil of the valley to an estimated depth of 1,800 feet.

Just south of the Mexican boundary line in the Imperial Valley there is a region comprising 30 to 40 acres where geysers are very active. This region is locally known as the "Volcanoes." On August 21, 1916, these geysers were in a state of great agitation. Mr. C. R. Rockwood, chief engineer of the Imperial Irrigation District, happened to be in the vicinity on that day. He described the disturbance as follows:

> The eruption occurred about 4 o'clock in the afternoon, and was the most violent I have ever observed during the many years I have been in this locality. The explosions lasted through a period of 11 minutes, during which time I presume there must have been 100 distinct explosions covering a lateral area 1,500 feet wide, each individual explosion being from 20 to 100 feet in width, throwing up columns of mud and steam to a height of 600 to 700 feet. Previous to this I have never witnessed one of these explosions that threw mud into the air to a height greater than 200 feet; while ordinarily the height is but 15 to 50 feet. The active explosions are in a submerged area, small in extent. This, however, is surrounded by a wider area of sulphur cones; while the hot sulphur springs extend for several miles both to the north and south of the more active center. There was no earthquake at the time.

In an investigation of gas rates conducted by the State Railroad Commission, a representative of one of the public service corporations operating extensively in northern California testified that earthquakes are a cause of leakage of gas from underground gas mains. As this loss is eventually borne by the consumer, it appears that the public interest would be served

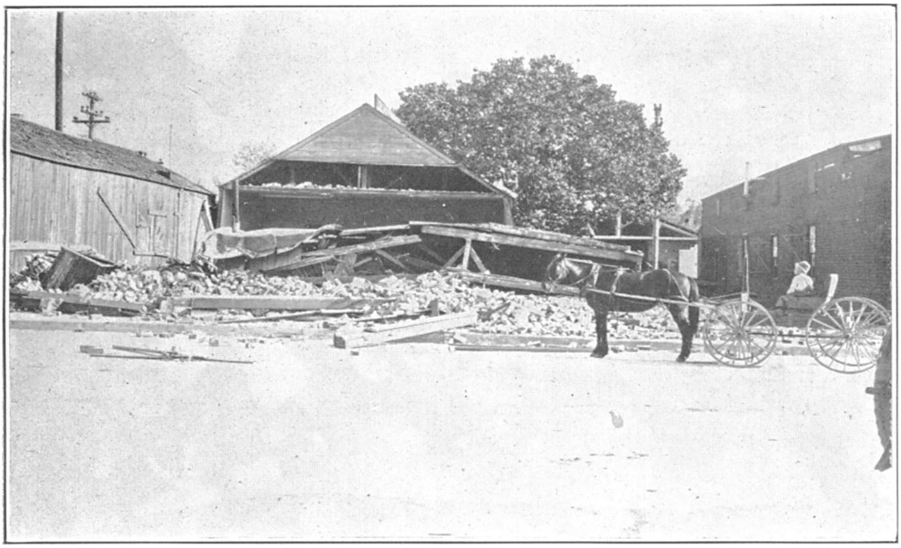


FIG. 13. BUILDINGS IN THE BUSINESS DISTRICT OF SAN JACINTO, CALIFORNIA, WRECKED IN AN EARTHQUAKE ON APRIL 21, 1918. (Photograph by Homer Hamlin.)

by a study of the problem, with a view of preventing the loss, if possible.

Earthquake insurance is in growing demand. However, owing to the absence of trustworthy statistics in the past, rates have been more or less arbitrary, and most of them have had no scientific basis. In a few years, however, it is hoped that more reliable data will be available on which to compute rates.

California has numerous astronomical observatories. It has occasionally happened that astronomers have detected earthquakes while observing a star through a telescope. Mr. Wendell P. Hoge, of the staff of the Solar Observatory of the Carnegie Institution of Washington located on the summit of Mount Wilson, California, noticed such an earthquake on March 22, 1916, while watching a star image in a 60-inch telescope. He reported:

> Oscillations of the star image in the field rapid and short at first, becoming more marked in the middle, and diminishing at the end of the disturbance. Evidently a very faint shock.

The most widely felt earthquake in 1917 occurred at 10:07 P.M. on May 27. In the Imperial Valley some damage resulted through the cracking of walls, people were much frightened, and at a school in Brawley where commencement exercises were in progress several women and children fainted as a result

of hysteria. Concerning this earthquake Mr. Hoge, of the Solar Observatory, reported:

> This earthquake was observed by Astronomer Dr. Harlow Shapley while observing with the 60-inch telescope. Star image oscillated rapidly back and forth in field of view in eyepiece. Two shocks close together were observed.

Various Japanese investigators have found that the barometric gradient offers a means of discovering unknown seismic zones or faults, as it was shown that the prevailing gradient at the time of an earthquake was nearly perpendicular to the fault. The method was found more feasible and more accurate than that of constructing the zones statistically by locating a large number of epicenters. In California, with well-developed barometric gradients occurring during the winter half-year, and with frequent earthquakes occurring throughout the year, this method offers an opportunity for some student of seismology to do useful work in locating fault zones which are still unrecognized.

San Francisco has learned its lesson in the matter of fire protection in a region of high seismicity. When that city was destroyed by fire in April, 1906, it was because the water mains had been broken by the earthquake, and there was no water available for fire-fighting purposes. The water system has

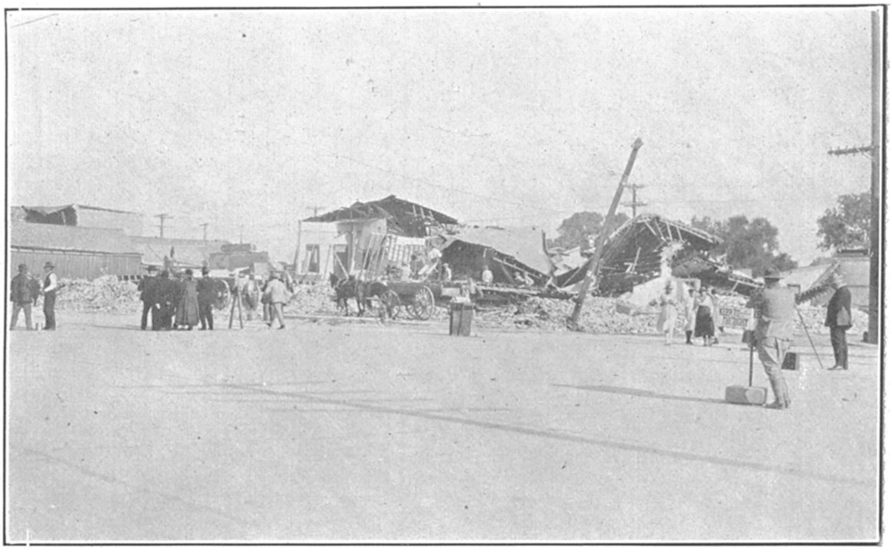


FIG. 14. STORE BUILDINGS IN THE HEART OF SAN JACINTO, CALIFORNIA, WRECKED BY AN EARTHQUAKE ON ARPIL 21, 1918. Because of the fortunate time of occurrence, at 2:32 o'clock on a Sunday afternoon, the business district was largely deserted, and no lives were lost. (Photograph by Homer Hamlin.)

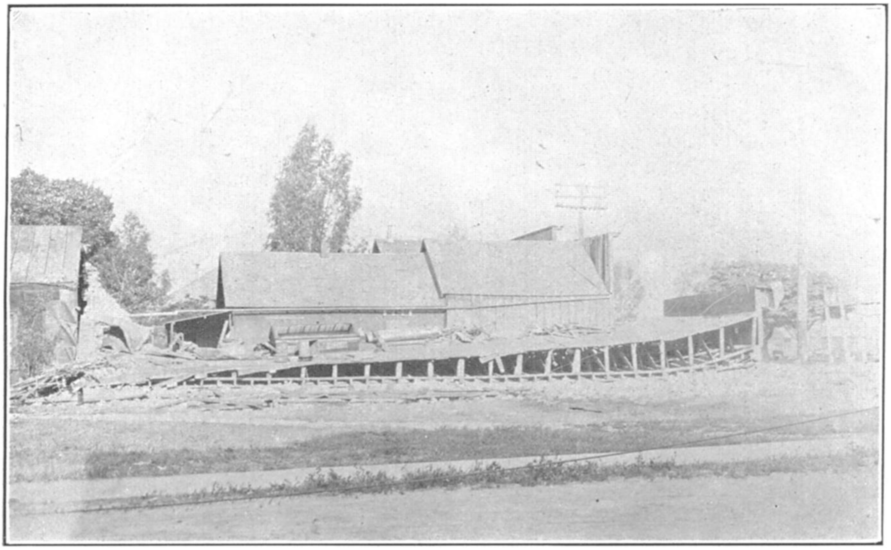


FIG. 15. A BUILDING ON MAIN STREET, SAN JACINTO, CALIFORNIA, WRECKED IN AN EARTHQUAKE ON APRIL 21, 1918. (Photograph by Homer Hamlin.)

been reconstructed in such a way that an earthquake could not destroy its efficiency. But in the matter of building construction, much is still to be learned. Steel-frame and reinforced concrete buildings will stand through a severe earthquake. Wooden buildings, too, will remain unharmed in destructive shocks, since they will yield to strains. Brick and concrete-block buildings are easily destroyed. But the most dangerous type of the construction is the primitive adobe, which is still in use among Mexicans and Indians. The lives lost in the Imperial Valley earthquake of June 22, 1915, resulted from the collapse of adobe buildings. In San Francisco the owners of certain steel-frame apartment buildings advertise their property as being "earthquake-proof." During the Exposition year, 1915, many visitors in San Francisco were disappointed in but one respect. They spent a week or two in that city without experiencing a single earthquake, whereas they came expecting to feel one at least every day. In the course of time laws will doubtless prevent the construction of projecting cornices in buildings, and the erection of overhead signs and electric wires in cities like Los Angeles and San Francisco, where a recurrence of severe earthquakes may be expected from time to time.

At 3:01 A.M. on July 6, 1917, an earthquake occurred in the Owens Valley which caused a break 160 feet long in the con-

crete flume of the Los Angeles aqueduct. Under the direction of Mr. William Mulholland, chief engineer of the aqueduct, the damage was temporarily repaired by bridging the break with steel pipe. Since that time the flume has been rebuilt and reinforced. The water supply in Los Angeles was not cut off, because the break occurred above the Haiwee reservoir, which has a capacity sufficient for the storage of several weeks' supply of water for the city. The city of San Francisco is now constructing a similar aqueduct which will eventually be 200 miles in length, bringing water to the city from the Hetch Hetchy Valley. As a result of the damage sustained by the Los Angeles aqueduct in this and in other earthquakes, reinforced and specially adapted construction is planned for the San Francisco waterway in those places where it will cross recognized fault planes.

The term "earthquake weather" is often encountered in California. Those who use the term are unanimous in referring to a condition of hot and calm weather, without much cloud, but usually with more or less haze and diminished visibility. The condition referred to is similar to that which precedes a summer afternoon thunderstorm in the Middle West. While many of the earthquake observers believe that there is an intimate relation between earthquakes and the weather, meteor-

FIG. 16. A CONCRETE-BLOCK BUILDING WRECKED BY AN EARTHQUAKE. Experience has shown that reinforced concrete, steel-frame and wooden buildings will stand through severe earthquakes, whereas brick, concrete-block and adobe buildings are easily destroyed. (Photograph by Homer Hamlin.)

ologists firmly maintain that there is no real relation. Professor W. J. Humphreys, of the Weather Bureau, believes that the apparent relation can be explained in terms of human psychology,—that the observer under the weather conditions described above is in a sensitive and expectant mood, with a feeling of apprehension, and hence feels slight earthquakes which under other conditions might pass unnoticed.

The attitude of the California newspaper editors toward the reporting and the publishing of earthquake data is curious. There seems to be a gentlemen's agreement among editors to omit all reference to the occurrence of earthquakes. Frosts, fleas and earthquakes are tabooed subjects. Such information does not attract settlers, nor does it aid in selling real estate. Perhaps it is for these reasons that seismologists receive neither sympathy nor support from the press. The general public promptly plunges into a kind of hysteria when a severe earthquake occurs, but soon relapses into complacent indifference when the immediate danger is over. Seismological research is therefore left largely to a few individuals like Dr. J. C. Branner, of Stanford University, the real founder of the Seismological Society of America, and who remains to-day the most enthusiastic student of seismic phenomena in America.

A discussion of California earthquakes would be incomplete if it did not attempt to correct certain false notions concerning the danger from earthquakes. While the seismicity of the state is acknowledged to be high, the highest in the United States, the actual danger to one living in any particular locality is small indeed. Though written almost 50 years ago, the following words of General Hardenburg, U. S. Surveyor-General in 1871, are still true:

> Reasoning from the foregoing historical facts, I am firmly of the opinion that the earthquakes of California are not so much to be dreaded as is generally supposed; in fact, that they are far less dangerous to life and property than are the hurricanes of the South, or the summer tornadoes of the North.